Multipacting in the ILC 1.3 GHz HOM Coupler

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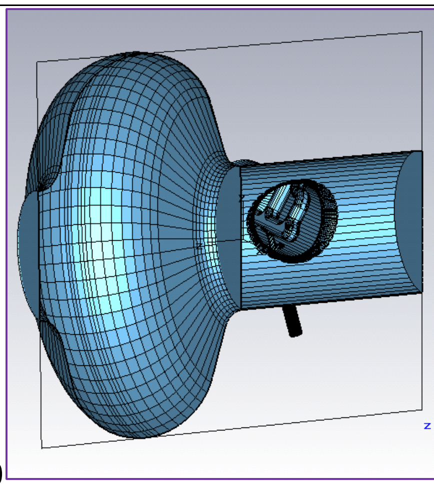
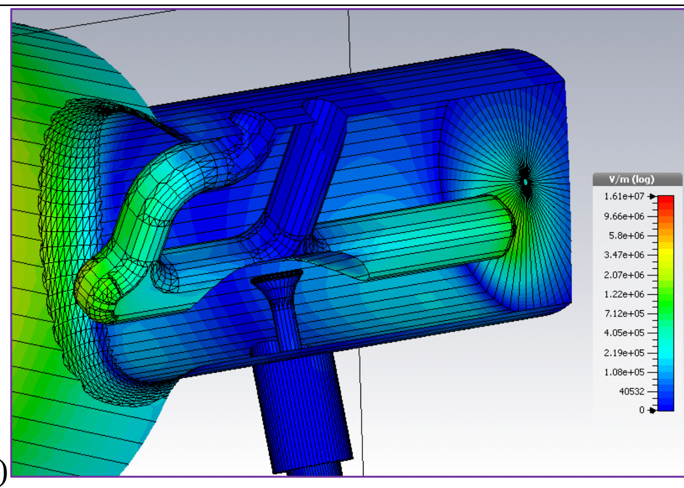
During high power tests of the 1.3 GHz ILC cavity on the test stand at TD an anomaly rise of temperature of the pickup antenna in the higher order mode (HOM) couplers was detected in accelerating gradient range of 5-10 MV/m. It was suggested that multipacting in the HOM coupler may be a cause of this temperature rise. In this work the suggestion is investigated.

Introduction

During high power tests of the 1.3 GHz ILC cavity on the test stand at TD an anomaly rise of temperature of the pickup antenna in the higher order mode (HOM) couplers was detected in accelerating gradient range of 5-10 MV/m. It was suggested that multipacting in the HOM coupler may be a cause of this temperature rise. The multipactor (MP) in the HOM couplers of TESLA-type cavities is a known phenomenon that was studied already in a number of works (see [1, 2, 3] for example). Because of the energy deposition of MP electrons at bombardment sites, the cavity wall temperature may rise. Taking into account this fact and also the behavior of the cavity during thermal runaway, it was suggested that MP may be a cause of the pickup antenna heating. Apparently the MP is not very powerful, since there is no noticeable temperature rise of the parts of HOM coupler besides the antenna. On the other hand the pickup antenna has much less effective cooling compare to the HOM coupler in general, so even a small energy deposition can heat it. Therefore we were searching MP in the given interval of accelerating gradients that would deposit energy directly in the antenna body.

The search of MP were performed with the use of CST Studio Suite. The electromagnetic fields inside the coupler were calculated by eigenmode solver. Then the properly scaled fields were imported in PIC solver and the particle tracking was performed using our usual approach [4]. The eigenmode HOM coupler model and the fields imported into PIC solver model are shown in Fig.1.


a)



b)

Figure 1: a) Eigenmode model of HOM coupler; b) Electric field imported into PIC model.

MP in the nominal HOM coupler geometry

At first the search of MP was performed in the HOM coupler of nominal geometry. In this geometry a gap of the HOM feedthrough ("coupling" gap) is of 0.5 mm corresponding to the drawings. Other important gap ("filter" gap) is used to tune filtering properties of the HOM coupler. This gap is about 2 mm (the end wall is not flat, so it is not possible to define exact distance). Both gaps are shown in Fig.2.

The sources of primary electron were placed in all possible locations of MP as shown in Fig.3. Secondary emission yield curve (SEY, also shown in Fig.3, b)) of the niobium was taken from the CST material library, and it corresponds to wet treated niobium. This surface treatment does not provide the lowest SEY, and apparently a real surface is much better cleaned. But the wet treatment data was chosen deliberately because high SEY helps to find all dynamically possible MP cases.

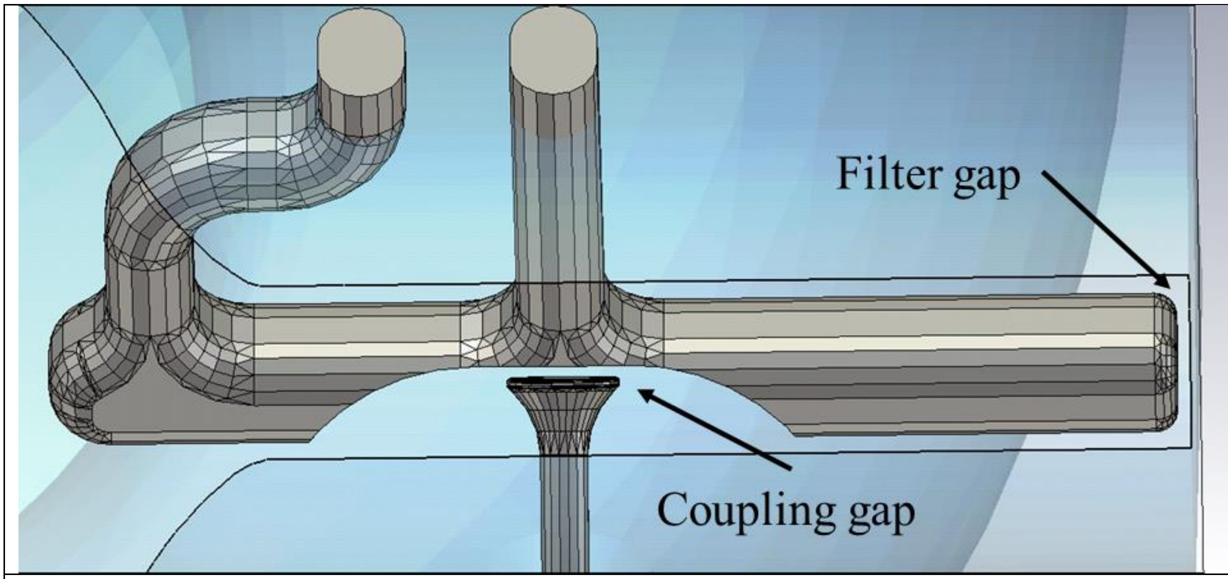


Figure 2: The gaps under consideration.

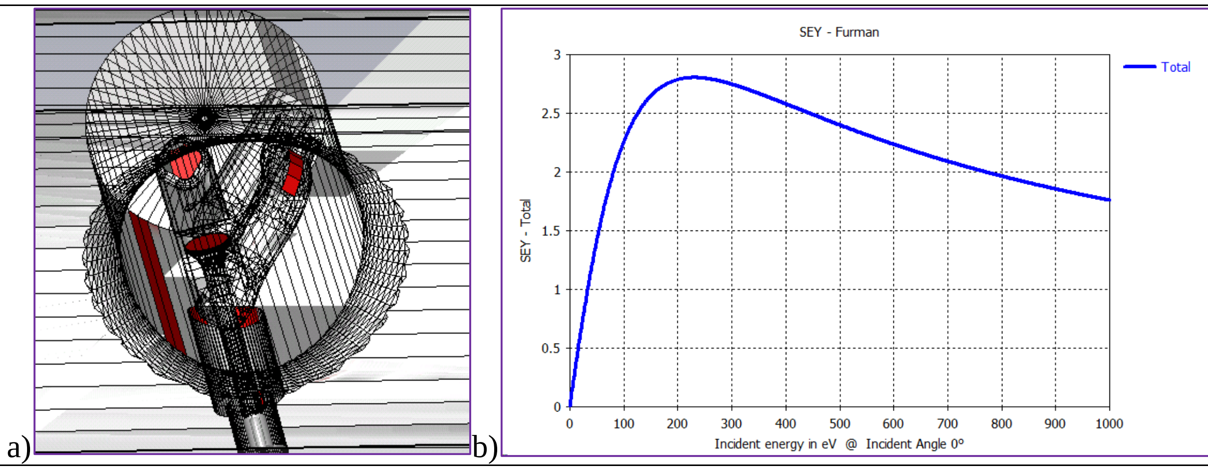


Figure 3: a) Locations of particle sources; b) Total SEY of wet treated niobium.

In general the simulations just confirmed what was found in the previous studies: there are three zones where multipacting develops at different accelerating rates (see Fig.4, a). The result in the form of <SEY> vs accelerating rate is shown in Fig.4, b), where <SEY> is a ratio of total emission current to total collision current averaged over last RF period of simulation. Value of <SEY> > 1 indicates particle multiplication. A new addition to the known results is a non-resonant MP, which develops in zone 2. Usually this kind of multipacting [5, 6, 7] is missed if simulations are performed with single-trajectory tracking codes.

But all these MP cases do not provide sufficient particle deposition on the pickup antenna (less than 0.1% of total collision energy) that could explain thermal runaway during high power tests. The positive potential on the antenna increases particle deposition by one-two orders, but there is no any justification to assume that some self-charging of the antenna due to particle bombardment may happen.

So, we may conclude that normally the antenna heating should not occur.

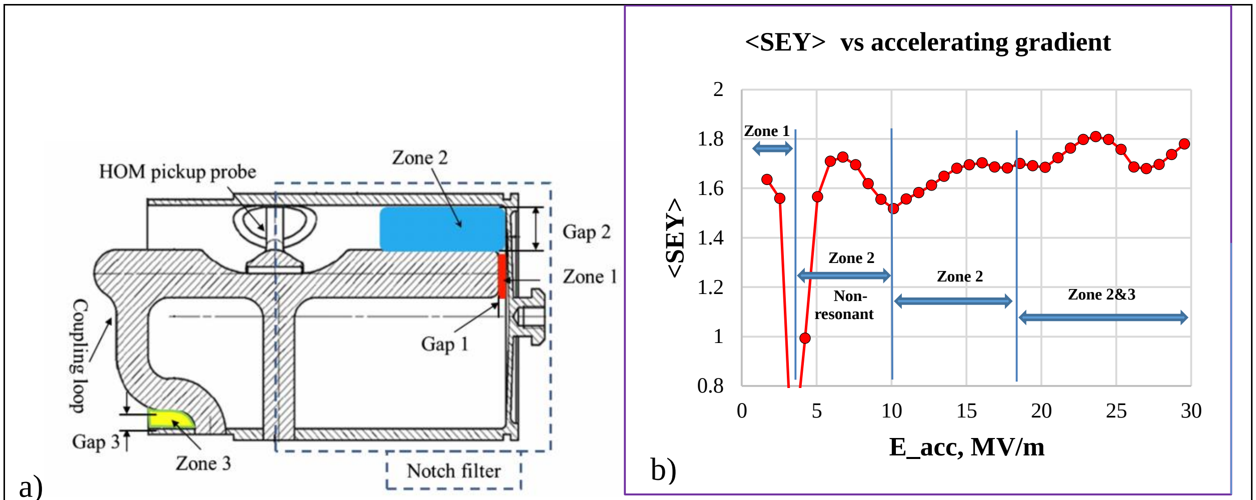


Figure 4: a) Locations of the known MP; b) General <SEY> of nominal HOM coupler.

MP in the coupling gap

The most natural MP case that could explain the antenna heating would be multipacting directly in the coupling gap. But for nominal gap size of 0.5 mm there is no conditions for multipacting since f·d < 80-90 MHz·cm, where f is frequency and d is size of the gap. This theoretical threshold of 80-90 MHz·cm is confirmed by many experiments, and MP of any type cannot exist below it [8].

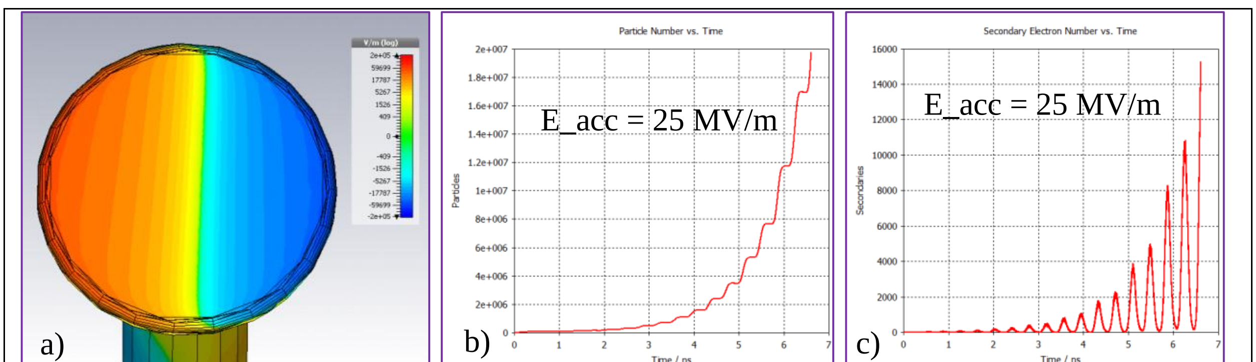


Figure 5: a) Normal electric field distribution on the antenna tip surface; b) Particle number vs time; c) Secondary electron number vs time

On the other hand in our case parameter f·d is very sensitive due to high frequency and exceeds the threshold already at d=0.615 mm. It is possible that such small deviation can happen because of inaccurate assembly, excessive etching or misalignment. Let's assume that the coupling gap is equal to 0.9 mm (the size is chosen to ensure an excitation of MP). The fields in the HOM coupler have been re-simulated with this gap size. The electric field distribution in the gap is extremely non-uniform – it even changes its sign (see Fig.5, a)). Nevertheless the resonance MP develops in the gap as expected, and the particle number dynamics for particular accelerating gradient is also shown in the Fig.5 b), c).

The <SEY> as a function of accelerating gradient simulated for d =0.9 mm (see Fig.6, a)) indicates minimal accelerating gradient at which MP starts as E_min = 14.35 MV/m. Since E_min ~ d, then for d = 0.615 mm MP would start at E_min = 9.8 MV/m. It is slightly higher than the high power tests demonstrated.

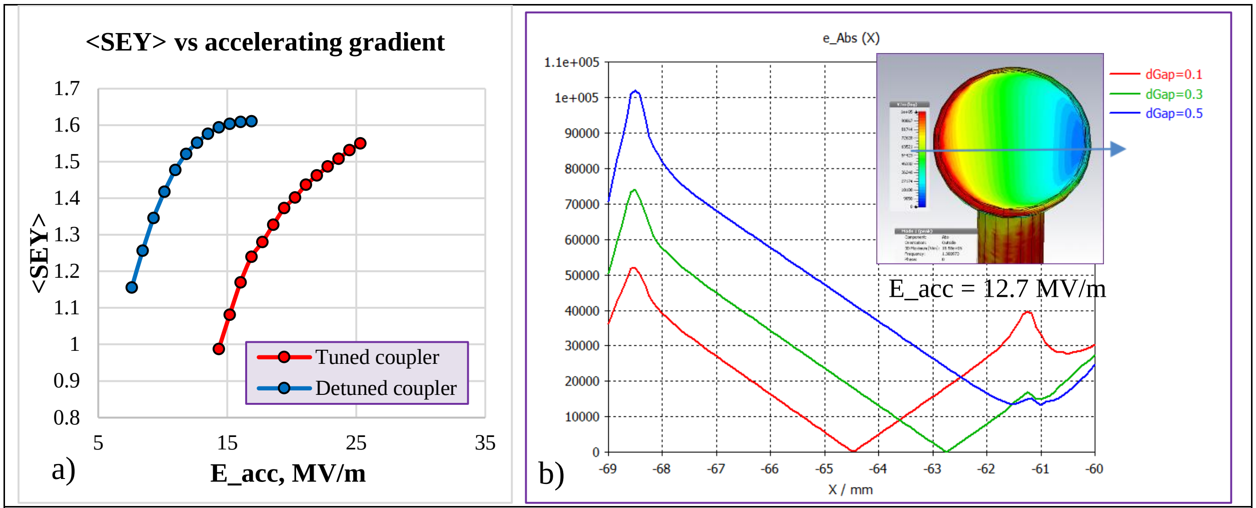


Figure 6: a) <SEY> vs accelerating gradient for tuned and detuned coupler; b) Distribution of absolute value of electric field across antenna tip for filter gap decreased by 0.1, 0.3 and 0.5 mm from optimal size.

A factor that can decrease E_min is a quality of HOM coupler tuning, i.e size of the filter gap. Properly tuned HOM coupler has minimal electric field in the coupling gap, and the field has zero line across the antenna tip (see Fig.5). Deviation of the filter gap size from optimal value shifts this zero line away and increases level of electric field (see Fig.6, b)). As a result E_min can be significantly decreased as shown in Fig.6, a) for the filter gap decreased by 0.5 mm.

Conclusion

This study showed that in properly assembled and properly tuned HOM coupler the known MP cases do not heat the pickup antenna. But it also demonstrated that a combination of coupling and filter gaps deviations can create conditions for specific multipacting in the coupling gap. This MP can be responsible for the antenna heating. To avoid this situation the nominal parameters of the coupler should be very accurately fulfilled. Other remedy is increasing of the coupling gap up to 1.5 mm. A larger gap shifts electric field interval where MP resonance conditions exist up to the level that cannot be reached under normal operation, while degradation of the damping efficiency for the most dangerous HOM is quite moderate (≈ 10%).

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